LIGHTING COLUMNS

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lighting columns

Research on the behaviour of lighting columns in sideways-on and head-on impact tests with private cars

INSTITUTE FOR ROAD SAFETY RESEARCH SWOV

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The Institute for Road Safety Research SWOV was founded in 1962. Its object is, on the basis of scientific research, to supply the authorities with data for measures aiming at promoting road safety. The information obtained from this scientific research is disseminated by SWOV, either as individual publications, or as articles in periodicals or via other communication media.
SWOV's Council consists of representatives of various Ministries, of industry and of leading social institutions.
The Bureau is managed by E. Asmussen, SWOV's Director. Its departments include: Research Policy, Research Co-ordination, Research Services, Theoretical Research Pre-crash Projects, Applied Research Pre-crash Projects, Crash and Post-crash Research and Information.
More information is to be found in the booklet Aims and activities, available at request from the Information Department SWOV.

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Preface

The Roadside Obstacles Research was carried out in order that the Interdepartmental Project Group of the same name, set up by the Minister of Transport and Public Works, could formulate recommendations with the object of making the area alongside the carriageway as safe as possible thus reducing the risk of accidents or serious consequences to a minimum.

The basic assumption for creating the safest possible roadside area is that a vehicle runs off the road on to the shoulder. The aim should be to arrange the roadside area so that the risk of an accident involving injury in such cases is as slight as possible. Dangerous objects such as poles and trees, and also (steep) embankments, should be fitted into the roadside area in such a way that their presence entails as little risk as possible to road users running off the road. There are three distinct types of roadside area, each providing a certain measure of safety.

In the first type, regarded as the safest of all, there are no hazard areas or obstacles. Vehicles leaving the road can go on running freely or perhaps can be brought under control again. Such an area, however, must provide sufficient support so that a vehicle running on to it does not roll over, and it must be wide enough.

The second type, which is not quite as safe, is that on which obstacles such as lighting columns, roadside telephone pillars and signposts are located. Such obstacles then have to be designed so that if hit by a car or a heavier vehicle they do not endanger the occupants. This requirement takes private cars as the basis because such obstacles – in absolute terms – are hit mostly by this category of vehicle. The possibility of protecting such obstacles for private cars is, moreover, the most practicable.
It thus seems as if only car and truck occupants are offered a reasonable degree of safety. But the safety of two-wheeler riders (especially motor cyclists and moped riders) is also served in this way. These necessary obstacles, if they cause little danger to cars, can simply be placed on the shoulder without, for instance, having to be protected by a roadside safety structure. This greatly reduces the risk of hitting an object in the shoulder. This is an important aspect particularly for riders of two-wheeled vehicles, because an impact with a roadside safety structure may have very serious consequences for this category of comparatively vulnerable road users.
Besides these, there are also rigid obstacles that are comparatively uncommon and cannot be made safe, such as piers of bridges or overhead sign structures. If these are fitted into the second type of roadside area, they will have to be located outside the safety area. Should this be unfeasible for any reason, they will have to be protected separately, for example with an impact attenuator or roadside safety structure of a given length.

The least safe of the relatively safe roadside areas is that where there is a hazard area too close to the carriageway, such as a ditch, a steep embankment or a row of rigid lighting columns. This should then be protected, for instance with a roadside safety structure. Such a structure is safe enough for private car occupants (SWOV, 1970; Beukers et al., 1972; Flury et al., 1973; Paar, 1973). But there is a great risk of severe, if not fatal injury to two-wheeler riders.

In 1971, as part of the Roadside Safety Structures research project, the first ad hoc tests were made with lighting columns, signposts, traffic signs, roadside telephone pillars, obstacle-impact attenuators. Accidents with fixed objects were also analysed in greater detail by reference to available accident statistics.

The Roadside Obstacles research started by reviewing and describing research discussed in the literature into the behaviour of obstacles upon impact. This literature study, finalised in 1973, also became an important part of the Roadside Obstacles report published by the OECD in 1975.
Partly as a result of the literature study, a start was made with subsidiary research on the relationship between collisions with obstacles on various types of roads and the distance between these obstacles and the edge of the road. This research will result in recommendations on the size of the obstacle-free area.

The Lighting Columns research was continued in order to ascertain what types of columns can be regarded as being low-aggressive for private cars in the event of head-on or sideways-on impacts. The results of this experimental research have been used by Rijkswaterstaat for recommendations to road authorities.

As a consequence of placing low-aggressive lighting columns, it emerged that if they are knocked over by an impact they may under certain condition be dangerous to other road users. SWOV investigated these hazards as well. A separate report was made on this research.

Besides reports and articles already published (see References) the following SWOV publications have already appeared or will be appearing on the subject of Roadside Obstacles:

1. Roadside obstacles; Literature study of research into the behaviour of obstacles upon impact (published in OECD, 1975, pp. 50-57; 89-119).
2. Lighting columns; Research on the behaviour of lighting columns in sideways-on and head-on impact tests with private cars (SWOV, 1978-2E).
3. Hazards with falling lighting columns; Considerations regarding the position of lighting columns low-aggressive for private cars (SWOV, 1978-3E).
4. Obstacle-free area; Research on the relationship between impacts with obstacles on various types of roads and the lateral distance between these obstacles and the edge of the road (SWOV, to be published).

The project leader for the Roadside Obstacles research, which is monitored by the Interdepartmental Project Group of the same name, is C.C. Schoon (Crash and Post-Crash Research Department SWOV).

Foreword

In the provisional issues of the Dutch draft guidelines on 'Roadside safety structures in Soft Soil' and 'Roadside safety structures on Bridges', of 30th August 1970, it was stated that rigid obstacles within 10 metres of the inside edge of the carriageway side-line on motorways should be protected by a roadside safety structure (see also SWOV, 1970). The motive was that rigid obstacles offer too much resistance to impacts by cars and may cause severe injury to the occupants and/or damage the vehicle very badly. Obstacles that are low aggressive for private cars, however, need no protection if placed inside the 10-metre area.

In order to avoid having to erect roadside safety structures purely to protect lighting columns, SWOV at the request of the authorities carried out experimental research to determine which types of lighting columns needed protecting and which did not. In other words: it was examined which types of lighting columns offer so little resistance when hit by cars that the occupants run no risk. If there is little risk of mechanical force otherwise affecting the impacting car's occupants, the lighting columns can be described as 'low-aggressive for private cars'.

In order to investigate which types of lighting columns caused no impact hazard to car occupants it was necessary to conduct impact tests.
In 1971, SWOV made a limited series of tests for the Rijkswaterstaat Working Party on Lighting Columns (SWOV, 1976). These impact tests, head-on only, were necessary in order to provide Rijkswaterstaat quickly with an idea of the resistance of lighting columns on the market at that time. For convenience, this publication will describe this series of ad hoc tests as test series A.
Next, from December 1973 to January 1975, SWOV made two series of tests at the request of Rijkswaterstaat. These tests series, B and C, relate to lighting columns tested in two different ways, i.e. with head-on and sideways-on impacts. So far, test series of any extent relating to impacts with obstacles had only been made head on. SWOV was the first institute to make reproducible sideways-on impacts. The equipment that made these possible was designed by the Research Institute for Road Vehicles TNO (IW-TNO), Delft (see also Schoon, 1978).
The type of test vehicle, impact speed and other test conditions were determined both from statistics and with the aid of descriptions of lighting column tests in the literature. The columns under test were placed so as to resemble the actual situation as closely as possible. The columns were also fitted out the same as in practice.

The impact tests were carried out at 'De Vlasakkers' proving grounds, Amersfoort, made available by the Ministry of Defence.
The tests were filmed by a team from the Foundation for Film and Science (SFW), Utrecht, led by W. van den Berg.

The high-speed films of speeds and decelerations were analysed by the Central Technical Institute TNO, Delft.
During test series B and C the measuring work was carried out by the Research Institute for Road Vehicles TNO, Delft.
The Soil Mechanics Laboratory, Delft, measured soil resistance in test series A.
The site work was carried out by the firm of Gebr. Kramer, Elst (Utrecht).

The lighting columns tried out in the test series were supplied by the following manufacturers:
Lips Aluminium B.V., Drunen
Nedal B.V., Nederlandse Aluminium Maatschappij, Utrecht
N.V. Fabriek en Handelsbureau Nederland, Haarlem
Nolte Mastenfabriek B.V., Maarheeze
Schott's Lichtmastenfabriek, Veendam
Vulkan A.G., Cologne, Germany

This publication has been compiled by the project leader for the Lighting Columns research, C. C. Schoon, and A. Edelman, Head Crash and Post-Crash Research Department, in collaboration with our Information Department.

The film Sideways-on and Head-on Impact Tests, made for SWOV by the Foundations for Film and Science, Hengeveldstraat 26, Utrecht, is obtainable at that address.

E. Asmussen
Director Institute for Road Safety Research SWOV

Introduction

Research on the behaviour of lighting columns hit by cars forms part of the type of research limited to the crash stage of the accident. Its principal objective is to prevent injuries, or to reduce their severity, in case of an accident. Knowledge acquired in such research may also be of great assistance in developing measures aimed at preventing (specific kinds of) accidents.

In the crash stage, there are basically two distinct types of impacts: primary and secondary. The primary impact is that by the *vehicle* with other objects, such as other vehicles or obstacles, which decelerate the vehicle. This deceleration leads to the secondary impact. This is the impact by the *human beings* (the driver and any passengers) with parts of the vehicle or, if they are ejected or flung off it, with other objects or with the ground.

In the secondary impact, for instance seatbelts in cars and crash helmets for moped riders and motor cyclists have a great influence in preventing injury or in lessening the severity of injury. In the primary impact, for instance, crush areas of cars are important, but especially the resistance of the obstacles with which the impact occurs.

Accident research has shown that a collision with a rigid lighting column can cause a serious accident.

The severity of a collision with a lighting column can be reduced by ensuring that in case of impact the shaft of the column separates from the root section at about ground level.

Two principles were examined in this connection: the breaking of aluminium columns at the base, and the use of a special safety design for steel columns. The latter consists of two flanges, one fixed to the shaft and the other to the root section. They are fixed together in such a way that they are separated by an impact.

Besides tests with steel and aluminium columns, a polyester column was tested which was not fitted out in any special way.

As stated, the principle applied with the non-rigid column – the low-aggressive column – is that it breaks off at the base or slips off from its foundation. This may cause the column to fall, for instance on the colliding vehicle, other road users or the carriageway. These implications were also examined. This aspect will be gone into further in the publication Hazards with falling lighting columns (SWOV, 1978-3E).

1. Design and execution of testing programme

Three series of tests were carried out. Test series B and C took place under the same conditions. The differences in these as compared with test series A are given in the relevant sub-sections and are summarised in Chapter 3, together with a discussion.

1.1. **Lighting columns**

1.1.1. *Test series A* (L1 to L10)

Test series A, carried out by SWOV in 1971 for the Rijkswaterstaat Working Party on Lighting Columns, was aimed at obtaining an idea at short notice of the resistance of the lighting columns then on the market.

The tests comprised steel columns with a light-point height of 10 m, i.e. a normal column (L1), one with a shear design (L4) and a light-weight column (L8). Owing to a technical defect, the soil resistance in the test with the normal steel column (L1) was less than in the subsequent tests. This type of column was therefore re-tested (L5).

Impact tests were also made with aluminium lighting columns with light-point heights of 10 m (L2, L7, L9 and L10) and 12 m (L3 and L6).

All the aluminium columns were designed for 3% top deflection under a wind load of 100 kgf/m^2. The steel columns had 2% deflection, except for the light-weight one (L8) which had 3%, like the aluminium columns. See Werkgroep Lichtmasten (Lighting Columns Working Party), 1972.

The tested columns had no electrical equipment nor a ground cable.

The dimensions and other details of these columns are given in Table A (See page 52); a full description of the tests is given in SWOV (1976).

1.1.2. *Test series B* (L11 to L30)

For this second series of tests, Rijkswaterstaat, the Provincial Bureaus of Public Works and a number of local authorities supplied details of the lengths of lighting columns which were to be erected in the next few years. The light-point heights were found to vary from 8 to 12 m, the emphasis in the provinces and local authorities being on the shorter columns (8 and 10 m) and in the case of Rijkswaterstaat on the longer ones (10 and 12 metres). The most common arm lengths were 1.50 and 3 metres.

Based on experience gained in test series A, it was concluded that if more detailed investigation on 10 and 12-metre columns would show that they suffice, this certainly would be the case with 8-metre columns.

The lighting column manufacturers were asked to supply 10 and 12 m columns which could reasonably be expected to have a low impact resistance. They would have to satisfy the static requirements of Rijkswaterstaat (RWS, 1972). Steel columns were then supplied with a slip design, and aluminium columns and a polyester column with no special features. Table B gives details of the various types of columns (See page 54).
The slip-design steel columns were supplied by different manufacturers, but were identical in the way they slipped off. As to the aluminium columns, each manufacturer used a slightly different process, but the mechanical properties of the material were the same.

Figure 1 shows a slip design: a flange is welded on to the bottom of the column which is connected with three bolts to the flange on the root section. The bolts are in V-shaped slots so that the flanges can separate if the column is struck. The torque of the bolts was in all cases 150 Nm. In two tests (L11 and L13) this slip construction was about 10 cm above ground level; this was later reduced to about 3 cm.
The columns were provided with electrical equipment, simulated lanterns and ground cables. In order to verify whether the impact would electrify the column or the test vehicle, the electrical equipment was connected to an electricity supply.
The root section of the columns were filled with sand up to ground level, which was the normal procedure.

One of Rijkswaterstaat's static strength requirements is that the top of a lighting column should not deflect under wind load by more than 4% of its light-point height (RWS, 1972). Static bending tests were made to check this. The column was secured horizontally and forces corresponding to the wind load were applied to the various parts.
All the columns tested in series B satisfied the 4% standard, apart from the 12 m aluminium column with the 3 m arm (L26) and the polyester column (L22).
The deflection of the polyester column was so great that the wall thickness and/or the base diameter would have to be greatly increased to get below the 4% standard. In order to judge whether this type of column might be regarded as a low-aggressive type, an impact test was made.

1.1.3. *Modification of standards*

The above-mentioned columns were used from September 1973 to March 1974 in a total of 21 tests: LT, L11 to L30 (for the description of the tests see 2.2.2.).
The results of test series B showed inter alia that, unlike those of test series A, the 10 m aluminium columns also had an impact resistance to be considered as too high.
The cause was sought, inter alia, in the diameter of the bottom section of the column which was greater in test series B than in test series A owing to the changed static-strength requirements. Furthermore, the columns tested in test series B were designed for large lanterns; only 5% of the columns erected by Rijkswaterstaat are equipped with these. If the static strength of the columns were to be based on columns with the lanterns used in 95% of the cases, this would reduce the area of the lantern by over 25%. This was taken as the basis for further tests. In order to make the column less aggressive still, it was decided to reduce the length of the arm from

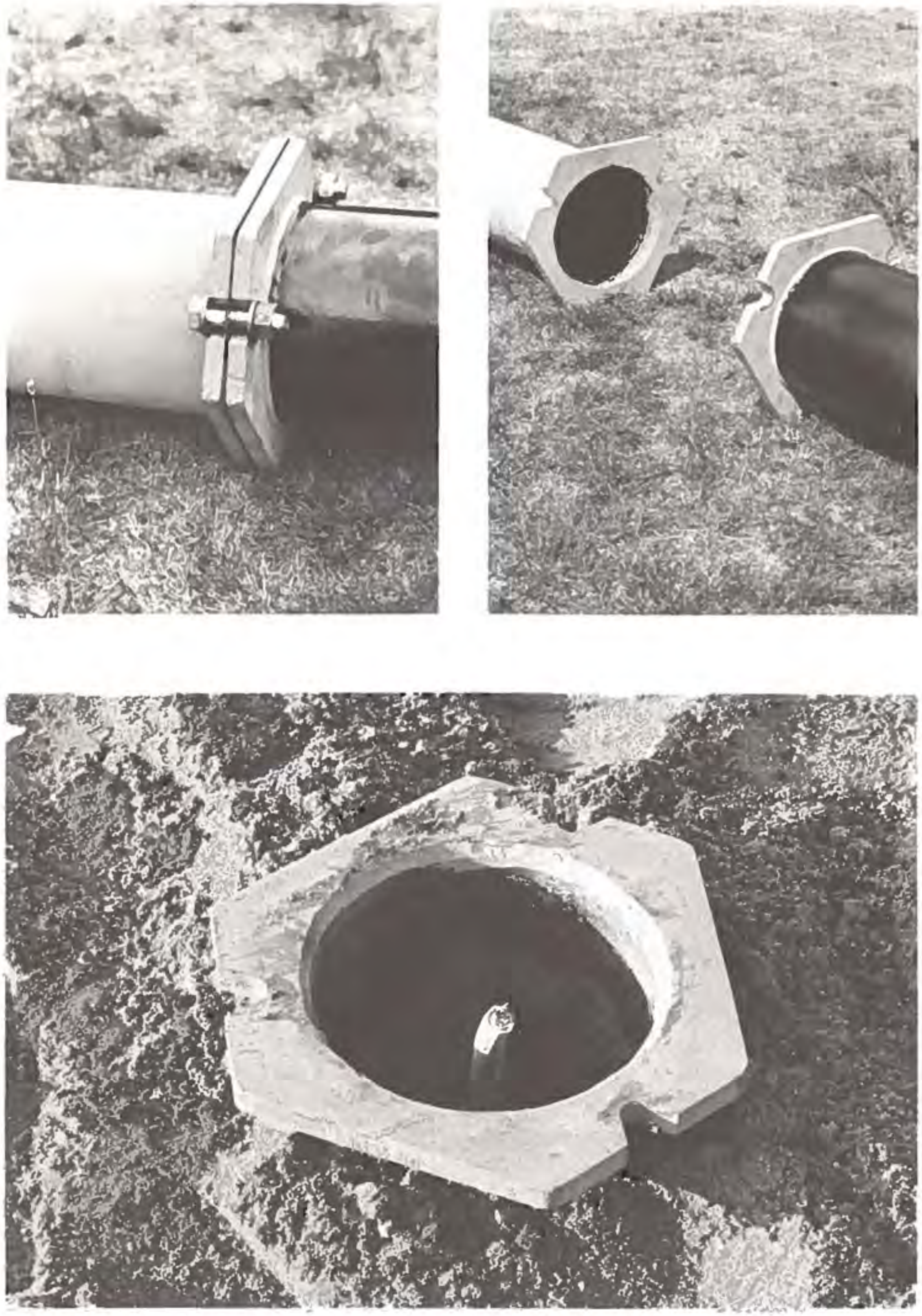


Figure 1. *The slip design was developed so that the column could separate from the root section in an impact under controlled conditions. For this, the root section and the column were fitted with flanges which can be bolted together. The root-section flange should be about 3 cm above ground level.*

1.50 to 1.25 m in conformity with the Netherlands Standards Institute standard (NNI, undated).

1.1.4. *Test series C* (L31 to L43)

With the adapted standards (RWS, 1974) calculations were made again for both the 10 and 12 m aluminium columns. They showed that the base diameter could be reduced by 12.5 to 20% with the same wall thickness or slightly greater.
The static bending tests did show that all the columns exceeded the 4% standard. In view of the slight excess of this standard in the case of 10 m aluminium columns, Rijkswaterstaat concluded that by changing the length of the column sections it should be possible to design such a column with a base diameter/wall thickness of 175/4 mm, which would then be satisfactory.
It was therefore decided to make a supplementary series of tests (C), which were carried out in January 1975 (L31 to L43). Further details of the columns are given in Table C (See page 56).
In all cases, as in test series B, the root section was filled with sand to ground level.

1.2. **Test vehicles**

It is known from the literature on lighting column tests (and from the laws of mechanics) that the greater the mass of an impacting vehicle, the less resistance it encounters from the column. The choice of vehicle type was therefore based on the principle that if results of impact tests with a lighter private car were favourable, then the results with a heavier car would be more favourable still. The weight category selected should be fairly represented in the total number of vehicles (See Figure 2).

In the first instance (test series A) 1960/1962 Opel Records 1700 were chosen. The empty mass of these cars is about 900 kg, putting them in the 800-1000 kg category, which at that time represented about 25% of all private cars. Since all the tests could be made with this type of car, the requirement of reproducibility was also met.

For test series B and C, the choice was the 700 to 800 kg category. This is now about 28% represented. The tests are therefore valid for vehicles in this category and those in heavier categories (55%). They are not as valid for vehicles in the under-700 kg category (17%). An effort was made to keep the vehicle mass as constant as possible. Building-in the instruments for recording decelerations, for instance, sometimes caused the stipulated maximum mass to be exceeded. The average mass for all vehicles in test series B and C was 770 kg.
In order to detect any difference in behaviour as between cars with front engines and rear engines in sideways-on impacts with a lighting column, such tests had to be made with both types. The ultimate choices were the Opel Kadett type B and the Volkswagen 'Beetle'.

Used cars were employed for the tests. The soundest possible bodywork was sought: firstly to ensure that the tests would be reproducible and secondly because sideways-on impacts the degree of denting is related directly to the rigidity of the body.

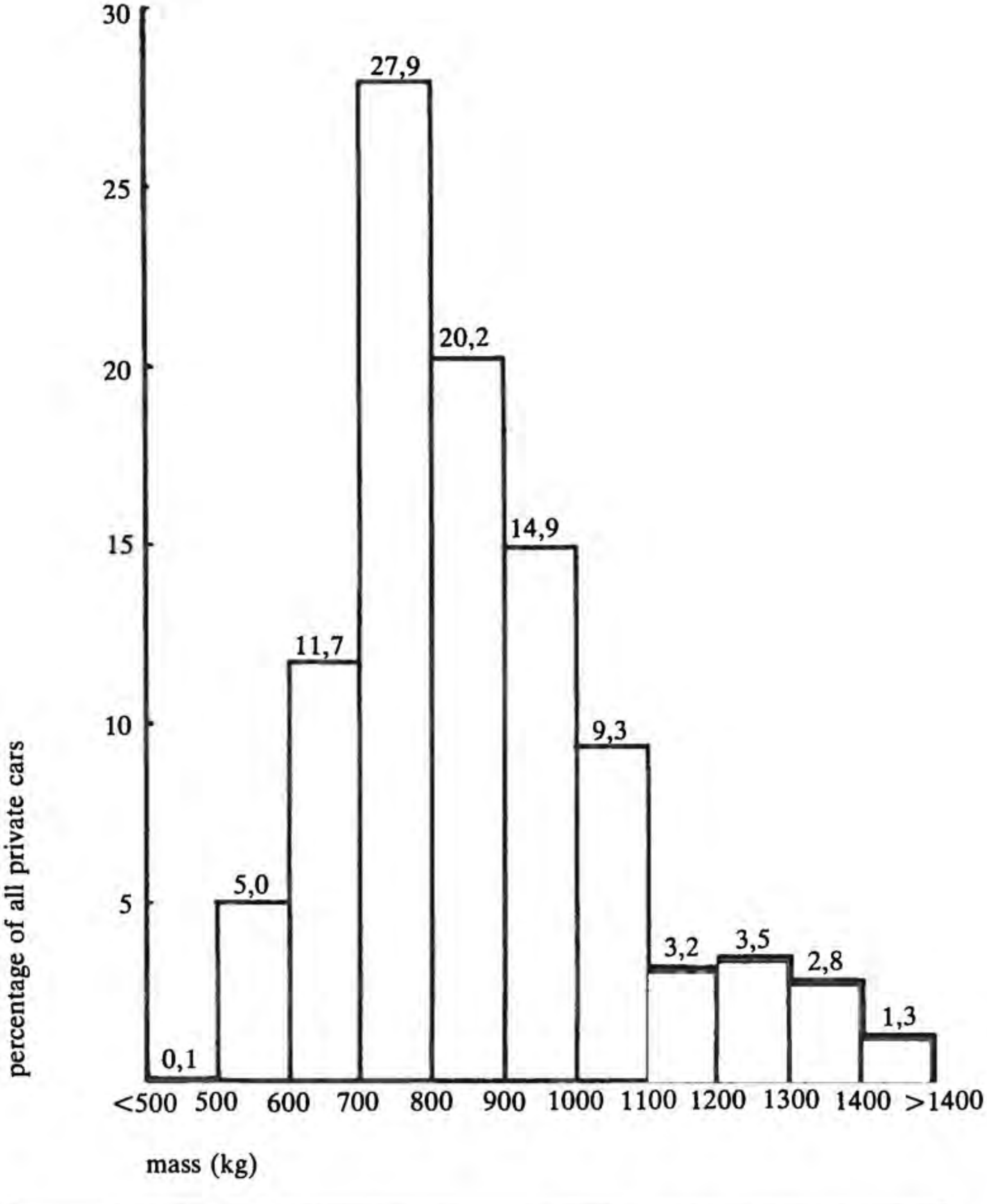


Figure 2.
Distribution (percentages) of private cars in 1975 in categories by weight (Source: Central Bureau of Statistics in The Netherlands (CBS)

1.3. Mode of impacting

Determination of the type of impact with a lighting column to be simulated at the proving grounds was based on accident statistics.

SWOV accident research has indicated the following distribution of types of collisions with trees and lighting columns: head-on 52%, sideways-on 21%, roll-over 9%, rear 4%, others/not known 13%. The main types are thus head-on and sideways-on impacts.

Owing to the limited objective, test series A comprised head-on tests only.

Research abroad (Edwards, 1969), however, has shown that in collisions with columns of an impact-attenuating design, sideways-on impacts have more serious consequences than head-on impacts. Although the number of accidents analysed in this research was not great, it did indicate that while the consequences of a head-on collision with a column may be satisfactory, this does not necessarily apply to a sideways-on impact.

On the basis of the above data, it was decided to include both head-on and sideways-on impacts in series B and C, with the emphasis on sideways-on.

In order to eliminate the influence of the test vehicle as much as possible in assessing the aggressiveness of the columns (with conditions as uniform as possible), the point of impact in all the head-on tests was the middle of the car. In sideways-on tests it was the front door.

The rotating movement of a skidding vehicle was not simulated. The effect of this, for instance on the direction in which the column falls, is not great since the direct impact takes place with a velocity component upon which the relatively slow rotating motion of the vehicle has little influence. As a guide: in American literature a 'normal' velocity of the rotating movement (yawing speed) is given as 0.6 rad/s.

1.4. Impact speed

In test series A an arbitrary choice was made of speeds of about 100 and 75 km/h. The tests with the aluminium 10 m columns also necessitated a test at about 30 km/h (L9) and one at about 50 km/h (L10), in order to examine the behaviour of these columns at lower speeds.

The results of test series A show, as is also known from the literature, that columns designed to break or slip off have a lower resistance at higher speeds. This contrasts with columns which do not (easily) break off; at higher speeds vehicle decelerations will also be greater. Since the further research was confined to columns which were assumed to break or slip off at the base, lower speeds might indeed be the most critical.

The second point is the position of the columns after impact. It was established in test series A that this can be predicted for low-aggressive columns hit at high speed; the column will fall in roughly the same path as that traversed by the test vehicle after the impact. At low speeds the column may fall sideways, however, with the danger of its dropping on to the carriageway. This hazard also had to be investigated experimentally.

The foregoing led to the maximum impact speed in test series B and C being put at 65 km/h and the lowest speed at 25 km/h. The intermediate speed was 45 km/h. In carrying out test series C, the 10 m aluminium columns were found to cause a greater vehicle deceleration at higher speeds. In order to examine whether this still applied at over 65 km/h, an extra test was made at about 80 km/h (L43).

1.5. Impact angle

The vehicle's impact angle with the column may affect the column's resistance to the vehicle. In the case of aluminium columns, both the position of the door opening and that of the cable opening may play a part and, in the case of steel columns, the triangular shape of the slip construction. In tests for which it must be possible to compare the results, a uniform impact angle must be adopted. This uniform angle is also important for establishing the position of the columns after impact. The angle can be ascertained from accident data.
Literature from other countries (Hutchinson & Kennedy, 1967; Garrett & Tharp, 1969) shows that for most vehicles running off the road the encroachment angle was less than 15°.
Although these American results do not necessarily apply to the Netherlands – and no better data are available – the position of the column in test series B and C was chosen so as to use an impact angle of 15°. In test series A it had been set (arbitrarily) at 10°.

1.6. Proving grounds

1.6.1. *General*

All the test were carried out at 'De Vlasakkers' proving grounds, Amersfoort, use being made of the existing facilities for testing bridge and roadside safety structures.
In test series A, the situation at the proving ground (See Figure 3) and the test method meant that the vehicle was often stopped by an earthen embankment, owing to which it sometimes overturned; in a number of cases it caught on the pulley of the driving mechanism. In other cases, too, the condition of the soil largely determined the run-off of the vehicle, and this was not therefore included in the investigations. The test assembly was modified accordingly.
Figure 4 indicates the proving ground as used in series B and C, with the tracks for head-on and sideways-on tests.
Similarly to test series A, the vehicles in test series B and C simulating head-on collisions were guided on rails and were pulled by a cable, and run into the lighting column.
For the sideways-on impacts a dolly was designed on which the vehicle is placed transverse to its direction of travel. The dolly is driven in the same way as the vehicle in the head-on tests. At the end of the track the dolly is suddenly braked and the

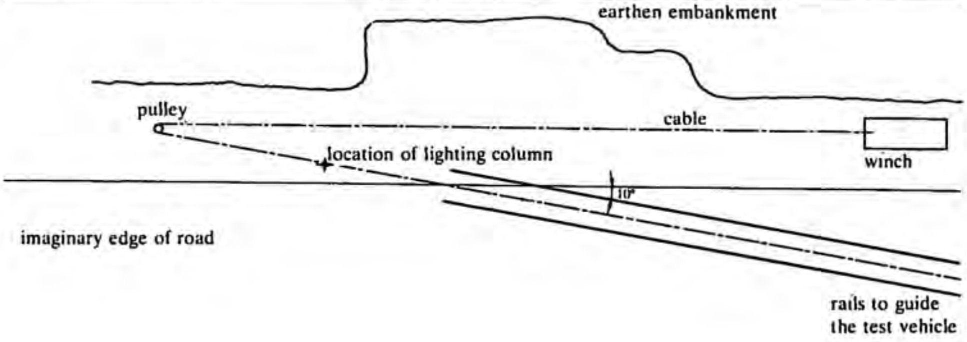


Figure 3. *Testing equipment for head-on impact tests (test series A).*

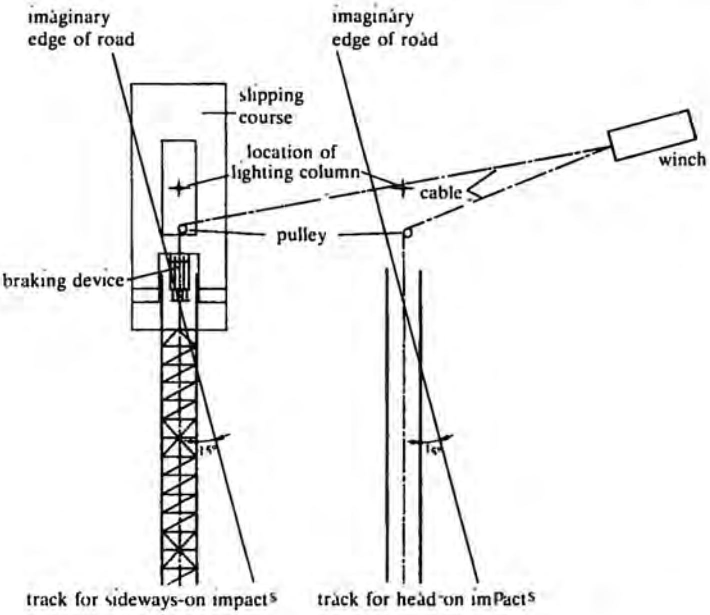


Figure 4. *Testing equipment for sideways-on and head-on impact tests (test series B and C).*

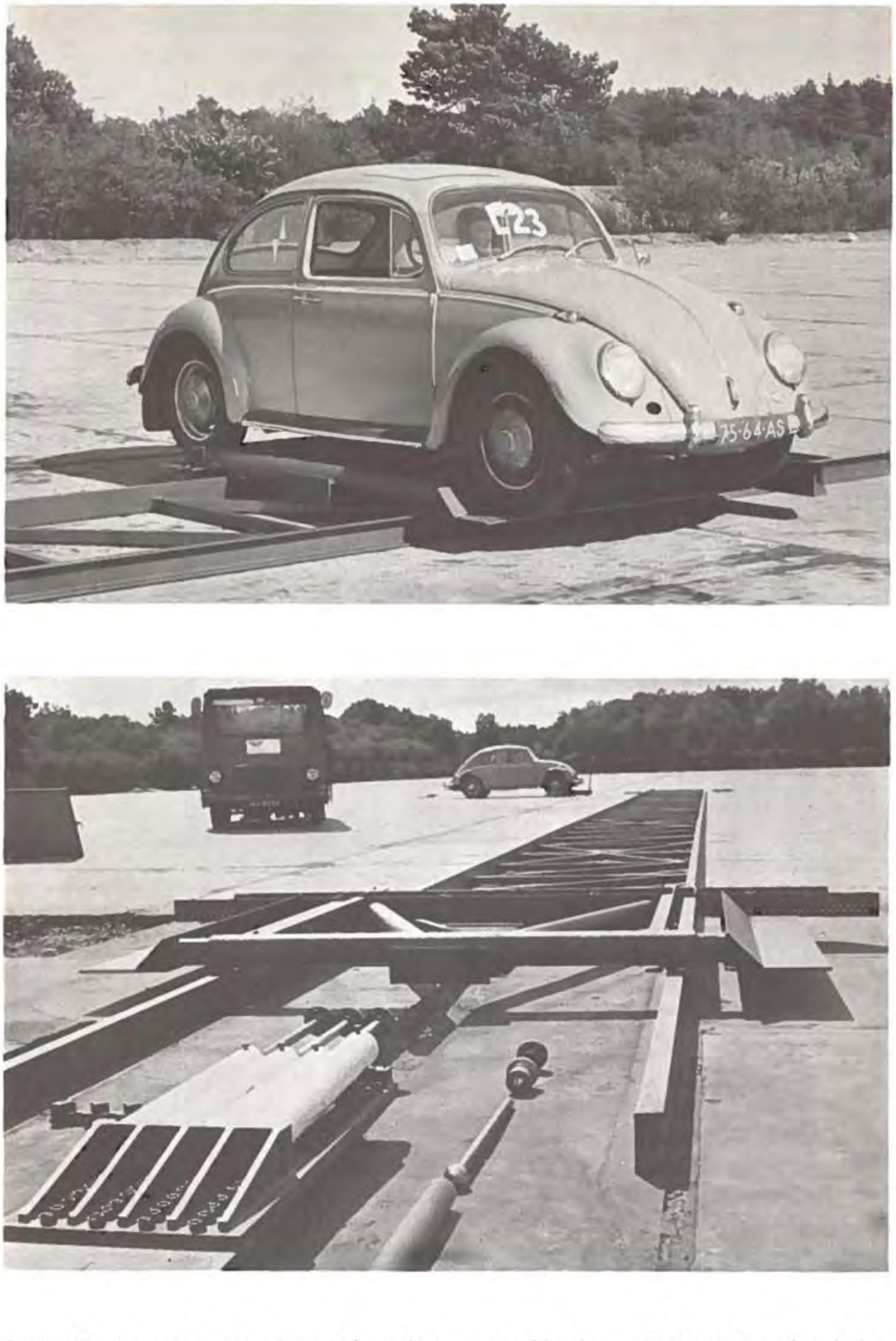


Figure 5. *Special equipment was designed for making reproducible sideways-on impact tests. The vehicle is placed transversely on a dolly which can be propelled along rails. At the end of the track the dolly is braked suddenly with a braking device; the vehicle slips off the dolly and against the object.*

vehicle slides off, travelling some metres laterally along slip strips before hitting the lighting column (Figure 5).

1.6.2. *Soil resistance*

All the tested columns were planted to a depth depending on their length and varying from 1.70 to 2.00 m. It is known in practice that a column cuts only slightly through the soil owing to an impact. In view of this and since the extent to which it cuts through the soil may determine the severity of a collision, an effort was made to limit this cutting through the soil in all the tests.
As the columns were always planted at the same spot, no natural compacting of the soil was possible and it was compacted with mechanical hand-rammers.
Reproducibility of the tests was assisted in test series A because the soil resistance round the column was checked prior to every test by the Soil Mechanics Laboratory (See Werkgroep Lichtmasten, 1972, Annex 6).
Owing to the moisture content of the sand, however, the soil could not be adequately compacted with (mechanical) hand-rammers. A limited degree of cutting through the soil was therefore obtained in test series B and C by placing a partition behind the column at the height of the cable opening. In order to obtain reproducible cutting through the soil and to prevent the column being damaged, a 5-cm thick polystyrene sheet was placed between the partition and the column.

1.7. **Test criteria**

If a column satisfied the criteria for vehicle deceleration and denting of the passenger's compartment, it is described as 'low-aggressive for private cars'.
Evaluation of the impact tests with lighting columns also devoted attention to the position of columns falling after an impact and the danger attributable to the electricity supply.

1.7.1. *Vehicle deceleration*

It has been found that vehicle decelerations in impacts are an important criterion for assessing the risk of injury to the occupants. The deceleration will never act in exactly one way. It is therefore necessary to have a standard which the combined decelerations must meet. Such a standard is the Acceleration Severity Index (ASI) of Ross & Post (1972 a and b).
The index, derived in Ross & Post (1972a), is:

$$\mathrm{ASI} = \sqrt{\left(\frac{g_{long}}{g_{long_a}}\right)^2 + \left(\frac{g_{lat}}{g_{lat_a}}\right)^2 + \left(\frac{g_{vert}}{g_{vert_a}}\right)^2}$$

long = longitudinal
lat = lateral
vert = vertical
index a = acceptable

The recorded vehicle decelerations are entered in the numerators of the formula. As values for these decelerations the average decelerations for a period of 50 ms are determined from the deceleration curves. This period should be chosen so that the average deceleration value is as great as possible. (To simplify the mathematical processes SWOV has added the additional condition for these series of tests that the maxima for the three periods – i.e. for longitudinal, lateral and vertical deceleration – must lie within a time interval of 50 ms. This condition is adopted on the assumption that in that case the decelerations can still be regarded as 'working together', thus having a combined effect on the vehicle's occupants).
The denominators are the vehicle decelerations 'acceptable' for human beings. For occupants *without* seatbelts, these are put at 7, 5 and 6 g longitudinally, laterally and vertically respectively. If the ASI value is not greater than unity, this indicates that the vehicle occupants will not be severely injured.

The formula should, however, be used with the necessary reserve. Firstly, because it is no simple matter to find the correct relationship between the risk of injury to the occupants and deceleration as long as dummies are not yet representative of human beings and as long as vehicle decelerations cannot yet be established on a large scale in real accidents. Secondly, differences in the features of vehicles may cause decelerations acceptable for human beings to vary considerably from vehicle to vehicle. But as long as there are no more scientific standards, the available standard will have to be used with some caution.

In view of the (fortunately) great increase in seatbelt wearing, it is interesting to indicate an ASI value acceptable for occupants *wearing* belts. As no such formula is known from the literature, values have been calculated with the aid of the ASI formula given above which can be used for seatbelt-wearing occupants and which can be substituted in the formula in the same way. Acceptable decelerations for seatbelt-wearing occupants were found to be 12, 9 and 10 g longitudinally, laterally and vertically respectively. These figures are, of course, also purely indicative.

Note 1
The design of lighting columns would have to be considered less critically as regards the crash aspects in fact, if it could be assumed that *all* vehicle occupants wore seatbelts. But as long as this is not so, for instance because in The Netherlands not everyone is compelled to wear them (for instance rear-seat occupants and occupants of cars built before 1971 are excluded), it first has to be examined which lighting columns satisfy the ASI criterion and which do not, when hit by cars with occupants *not* wearing seatbelts.

Note 2
For comparison of column resistances in head-on and sideways-on impacts, expressed as vehicle decelerations, the direction of the longitudinal deceleration was chosen for calculating the ASI in all tests so as to correspond with the vehicle's direction of travel. In sideways-on impacts, however, the risk of severe injury is undervalued as compared with head-on impacts with the same ASI value. In other words: for sideways-on impacts an ASI calculated in this way would have to be slightly less than unity in order to produce little risk of severe injury in such an

impact. This, moreover, is taken into account only in assessing whether a column has to be regarded as low-aggressive or not.

1.7.2. *Denting of passengers' compartment*

The ASI criterion takes only vehicle decelerations into account. But denting of the passenger compartment also increases the risk of injury. If the occupants' seating accommodation is made smaller, which means in a sideways-on impact that the *inside* denting at the height of the middle of the door exceeds 10 cm, this is assumed to influence the risk of severe or more severe injury. This measure is based on the requirement laid down for the Experimental Safety Vehicle project. It is also assumed that if in a lateral impact the cross-section of the door is reduced by about 5 cm, the seating accommodation will then be reduced if the dent measured *outside* is greater than about 15 cm.

A column broken or slipped off by an impact may fall on to the vehicle's roof. The dent it causes must not be too deep, because the occupants might otherwise be injured.
A requirement drawn up by Schlechter (1970) for the Experimental Safety Vehicle project says that the roof dent must not exceed about 8 cm (3 inches). This requirement would also seem suitable for The Netherlands.

1.7.3. *Position of the fallen columns*

Columns designed to break or slip off easily in case of impact may be flung forward or may fall to one side and drop on to the carriageway. The position of the fallen column was noted after each test. It was assumed that the edge of the paved road section corresponds to a line drawn at an angle of 15° to the direction of encroachment 1.5 m from the site of the column. The data from test series A were adapted for this purpose.

1.7.4. *Electrical part*

Columns low-aggressive for private cars should be examined to check whether they are electrically safe. If such a column is hit, the ground cable may easily be exposed with the risk of the column or the car being electrified. Nor is it ruled out that fire may be caused by a short circuit and, for instance, a petrol pipe being hit.
In test series B and C the electrical equipment was electrified via a main fuse and a fuse in the column in order to assess these aspects. (The electricity was supplied by a 220 V, 40 kW generator).

1.8. **Records**

The tests were filmed by at least three cameras, one of them high-speed (400 frames a second). Radar was used to verify the vehicles' speed. The final situation was photographed, measured and recorded in writing.

In test series A, the speeds and decelerations were determined by analysing the high-speed film. It was read frame by frame, and then averaged over three measurements. From these averaged values the speeds and decelerations were calculated, and with the aid of these the deceleration curves were plotted (See also SWOV, 1976). For the processing procedure see SWOV (1971).
As the lateral deceleration could not be measured in these test series A the term glat/glata in the formula for calculating the ASI is omitted.

Test series B and C, in which lateral deceleration was measured, showed that the influence of this was not great. The ASI values given for test series A (See Table A, page 52) will in most cases be a little lower than if Ross & Post's complete formula were used.

To determine the decelerations in test series B and C, two triaxial accelerometers were fitted in the test vehicle, one at the centre of gravity and the other in the luggage boot. As an experiment, one was also fitted in the chest of a dummy.

To compare the results from test series A with those for test series B and C, high-speed films were made of various head-on tests in addition to the electronic recording. Deceleration curves have also been determined from these by means of a modified analysis method (See SWOV, 1972).
Owing to failure of the electronic equipment no decelerations could be established for a number of sideways-on tests (L20 to L23). Data for other tests were used in order to determine the severity of the impacts still (See further 2.1.).
In tests L18 and L19 use had to be made of decelerations obtained from high-speed film analysis.

2. Test results

2.1. **General**

Tables A, B and C give the results for steel and aluminium columns and the polyester column tested in series A, B and C (See pp. 52 et seq.).

These tables give the ASI (Acceleration Severity Index) for occupants both *with* and *without* seatbelts. The relative decelerations values are to be found in the appropriate SWOV reports.

As stated in section 1.8., lateral deceleration was not measured in test series A. It could not therefore be used in the formula for calculating the ASI. The ASI values given in Table A will therefore mostly be slightly lower than if the complete formula were used.

In four cases in Table B (L20, L21, L22 and L23) an exact ASI value could not be given because the electronic equipment did not work. In all these tests the vehicle stopped against the lighting column. In three cases (L21, L22 and L23), the impact speed was about 45 km/h and in one case (L20) 27 km/h.

Based on the results of other tests, it can be said that in an impact in which the vehicle is abruptly stoped from a speed of about 45 km/h, the ASI without seatbelts is far higher than unity and with seatbelts is about unity. If the vehicle is abruptly decelerated from about 25 km/h to zero, comparable tests showed that the ASI without and with seatbelts was about unity and less than unity respectively. The table uses the terms greater than, smaller than and about equal to unity. The table also indicates whether the columns with the slip design did or did not slip off and whether or not the other columns were broken off by the impact. It is also stated whether the vehicle stopped against the column or whether it overturned.

2.2. **Aggressiveness of lighting columns as regards deceleration**

2.2.1. *Test series A*

Steel columns (with and without slip design)

The two normal steel columns (L1 and L5) offered so much resistance in head-on impacts that the ASI standard for acceptable vehicle deceleration was greatly exceeded. The lighter steel column (L8) also offered too much resistance to the test vehicle during the impact.

For the steel column with the slip design (L4), the deceleration remained below the limit. Based on this test, it was stated with some caution at that time that such a design presented good prospects of reducing the impact resistance of lighting columns to private cars.

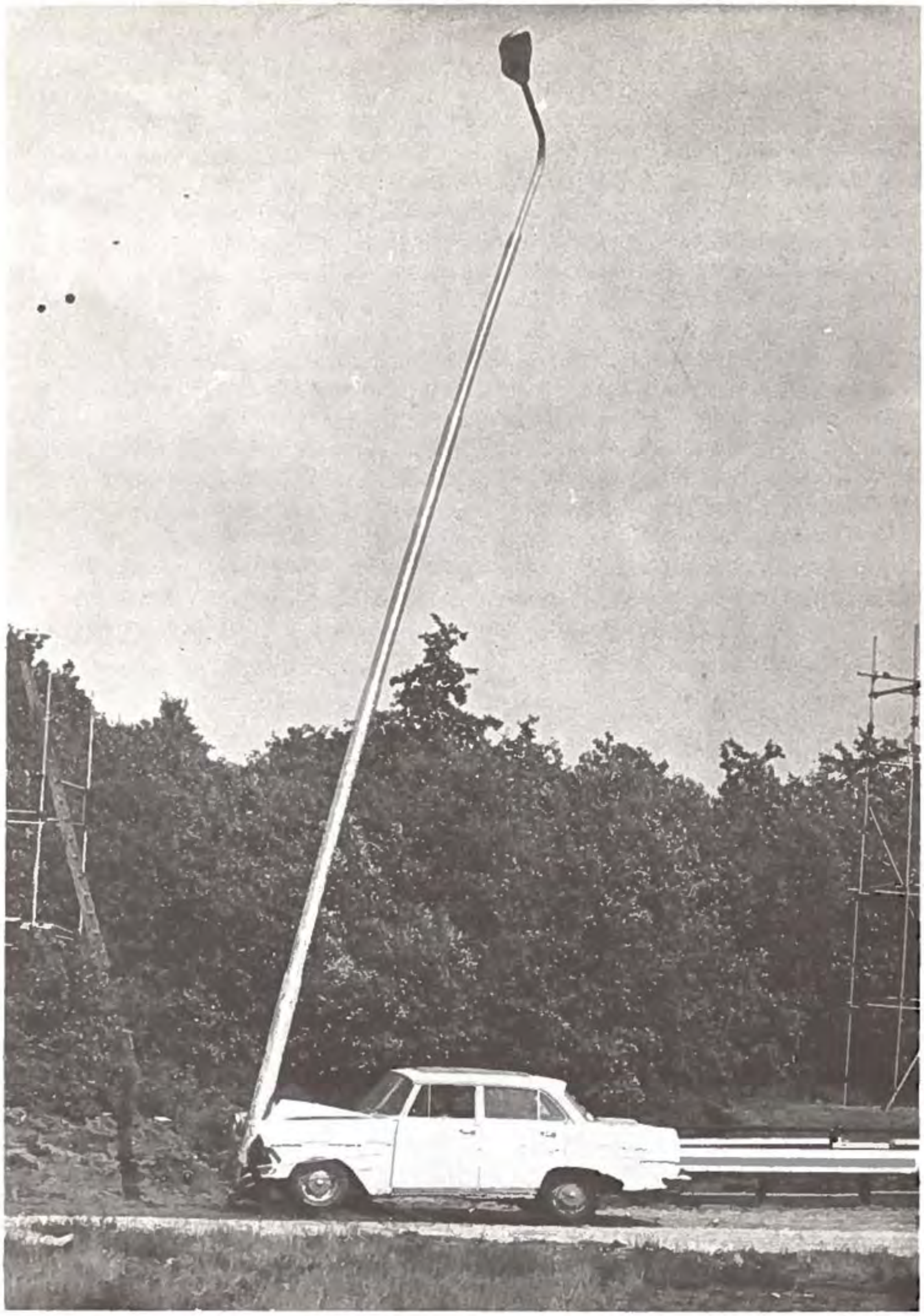


Figure 6. *This 12 m aluminium column was hit head-on in test series A tests at 70 km/h. It broke at the bottom of the door opening. The root section did not break but was flattened near the cable opening.*

Aluminium columns
It was found for all the tested aluminium columns in test series A that the shaft of the column was broken by the impact at the height of the door opening. The root section of the columns was pulled so far out of the ground in five of the six cases that the cable opening was at about ground level. As the root section was weaker at this cable opening, the columns broke (L7, L2) or bent over (L10, L9, L6) at this point.
The 10 m columns with a wall thickness of 4 mm broke off completely at the cable opening at vehicle speeds over 65 km/h and broke partly at lower speeds. In the cases in which there was a complete break at the cable opening (L7 and L2), the resistance met with by the vehicle was less than when there was only a partial break (L10 and L9). In all four cases the ASI without seatbelts was below the limit.
The wall thickness of the 12 m columns was 1 mm more than of the 10 m ones. Consequently, the root section did not break, but was folded flat at ground level (L3) or at the cable opening (L6). In both tests (L3 and L6) deceleration exceeded the limit.

A fuller description of the tests in this series is given in SWOV (1976).

2.2.2. *Test series B*

Steel columns without slip design
In a sideways-on test (L12) this steel column showed a very high ASI. The test vehicle stopped against the column, with a very big dent in the passengers' compartment. The column was bent over about 15°.

Steel columns with slip design
Eight steel columns with a slip design, two of them with a light-point height of 10 m and six with one of 12 m were tested – with one exception – with sideways-on impacts.
Both the 10 m column with a single arm (L16) and that with twin arms (L17) offered very little resistance to a sideways-on impact at about 40 km/h (ASI without seatbelt: 0.3).
The 12 m columns with a 1.5 m arm were tested in sideways-on impacts at 25, 40 and 57 km/h (L11, L15 and L14 respectively), and in a head-on impact at 46 km/h (L19). Here, too, very low ASI's were found. These showed that for columns offering little resistance the impact speed apparently has little effect on the extent of this resistance. It was also found that columns hit both sideways-on and head-on at comparable speeds (L15: 40 km/h and L19: 46 km/h) showed no major differences in deceleration values (ASI without seatbelt 0.3 and 0.4 respectively).
The 12 m column with a 3 m arm (L25), was the only one with a slip design, that showed a deceleration that was just not acceptable for occupants without seatbelts (ASI = 1.1). But the value is acceptable for occupants wearing seatbelts (ASI = 0.6). A possible cause of the greater deceleration is the greater mass of the column (about 35 kg heavier than the other 12 m columns).

Note
When slip-design lighting columns are erected, it should be borne in mind that the distance between the slip construction and ground level has to be very slight. In one

of the first tests (L13), the slip construction was 10 cm above ground level with the result that in a sideways-on impact in which the test vehicle's body heeled right over the lower flange of the column stuck behind the car's underbody. This caused a deceleration, therefore, over twice the acceptable limit. With the slip construction 3 cm above ground level there were no further problems in the other tests either with sideways-on or head-on impacts.

Aluminium columns

The tests with aluminium columns were started in test series B with columns designed for large lanterns (i.e. for heavier windloads and hence more robust columns) with which 5% of the columns erected by Rijkswaterstaat are fitted. If these columns were found to be satisfactory impacts, lighter columns would most probably be satisfactory as well.

But the results were poor. In the six tests made with 10 m columns both sideways-on and head-on (L21, L23, L27, L28, L29 and L30), the column met the ASI standard only in the last (head-on) test. None of the three 12 m columns tested (L18, L20 and L26) was satisfactory. In the case of the 12 m column with a 3 m arm (L26) a relatively large base diameter and a thin wall were used in an attempt to make the column break off more easily. Although it broke near the door opening, vehicle deceleration was too high.

Polyester column

The polyester column (base diameter/wall thickness at ground level 275/10 mm) impacted sideways-on at 45 km/h (L22) broke off at the height of the door opening, the upper part of the column bending over in the direction of driving. The lower part remained upright in the soil with the consequence that the test car came to a stop against it.

Although the electronic measuring equipment did not function properly in this test, it can be assumed on the basis of section 2.1. that the ASI for occupants not wearing seatbelts was more than unity and at least unity for occupants wearing them.

The results of the static bending tests moreover showed that this column would have to be built more robustly to satisfy the static strength requirements. If such a column is required to be low-aggressive it should break off at ground level or near the cable opening like aluminium columns.

2.2.3. *Test series C*

Aluminium columns 10 m

As test series A had shown that a 10 m aluminium lighting column with a base diameter of 190 mm offered little resistance, it was an obvious step to examine whether the dimensions of the columns could be reduced to those in test series A. It was decided to adapt the static strength requirements for the columns in test series C, by starting from smaller lanterns and shorter arms, giving a base diameter even less than that of the columns tested in series A. For comparison: the base diameter/wall thickness of the 10 m aluminium columns in test series A, B and C were 190/4, 200/4 or 220/3.75 and 175/4 mm respectively.

It also proved to be possible to make the 12 m aluminium column lighter, and this was re-tested a number of times. The results of test series C are given in Table C (page 56).

Of the *sideways-on* tests with the 10 m aluminium columns, the ASI without a seatbelt proved to be less than unity only in the low-speed test at about 30 km/h (L42). In this test the column did not break and the car came to a stop against the column.

The higher speed test at about 50 km/h (L41) proceeded as follows. The column broke at the top of the door opening, leaving the root section sticking about one metre out of the soil. This root section bent at the cable opening but still offered so much resistance that the test vehicle overturned. The ASI without seatbelts was 1.7, which is too high. (The ASI with seatbelts was calculated as 1.0).

In test L40 (L41 was a repeat) the column split all along its length when hit, with the result that it did not break off entirely at the door opening. The results of this test, like those in which the columns were inadvertently filled with too much sand (L31, L32 and L33) have been disregarded in the conclusions.

In the four *head-on* tests with 10 m aluminium columns (L35, L36, L37 and L43), their resistance was at first greater as the impact speed was higher, but decreased thereafter. There is thus a speed range in which resistance is greatest and not acceptable for occupants without seatbelts according to the calculated ASI (at an impact speed of 64 km/h (L35): 1.2 and at 76 km/h (L43): 1.1.). It may be assumed that no acceptable ASI's will be found in the range from about 55 km/h to about 80 km/h, at least for occupants without seatbelts. Only on the assumption that the occupants do wear seatbelts will these 10 m aluminium columns satisfy the ASI criterion in a collision.

In these tests, the root section was filled with sand in all cases. Whether the results would be better without sand will be examined in sub-sections 3.3.3. and 3.4.

In these head-on tests the column broke at the door opening in all cases. In the higher-speed tests the root section was flattened against the ground so that the vehicle could drive over it. In the lowest-speed test (L36: 30 km/h), the vehicle's kinetic energy was inadequate for it to run right over the root section and it came to a standstill; the ASI without seatbelts remained below unity.

Aluminium columns 12 m

The sideways-on impact test (L34) and both the head-on tests (L38 and L39) gave unacceptable ASI's without seatbelts. Under the applied test conditions the combined decelerations with these columns are lower than unity according to the criterion 'ASI with seatbelt'.

In the sideways-on impact the column broke at the top of the door opening. The stump still in the soil, however, was so resistant that the car came to a stop against it.

In the two head-on tests the column also broke at the door opening, but in one case the root section was flattened so much that the vehicle ran right over it. In the other case, the car stuck half way over the stump.

For the rest, all 10 and 12 m aluminium columns tested in series C failed to satisfy the 4% static strength standard (See also Chapter 4).

Figure 7. *This 10 m slip-design steel column hit laterally in test series B at 42 km/h, gave low vehicle decelerations. It fell on the car's roof; both sideways and roof dents remained within the maxima.*

Figure 8. *This 10 m aluminium column hit sideways-on in test series C at 30 km/h gave acceptable vehicle decelerations. But it did not break; the vehicle came to a stop against it. The dent in the vehicle's flank exceeded the maximum.*

2.3. **Aggressiveness of lighting columns as regards denting of passengers' compartment**

In sideways-on impacts, not only the ASI but also denting may influence the degree of injury to the occupants.
In four sideways-on impact tests in which the calculated ASI's without seatbelts were less than unity, the sideways dent in the vehicle at the height of the front door exceeded the 15 cm maximum adopted. This was found in two cases of steel columns with a slip design in which the excess was 3 cm (L11 and L14) and in two cases of aluminium columns in which the excess was 11 and 8 cm (L32 and L42 respectively). These figures are on the high side. One factor was that the bodies of the test vehicles were not all sound. This has considerable influence on the size of the dent, especially in a sideways-on impact.
Denting at the front did not reduce the size of the passenger compartment in any of the head-on tests.

The maximum dent caused by columns falling on the roofs of test vehicles was about 7 cm. This is just under the American standard of about 8 cm. Of the columns falling on the roofs of the test cars, the greatest mass of the shaft was 138 kg.

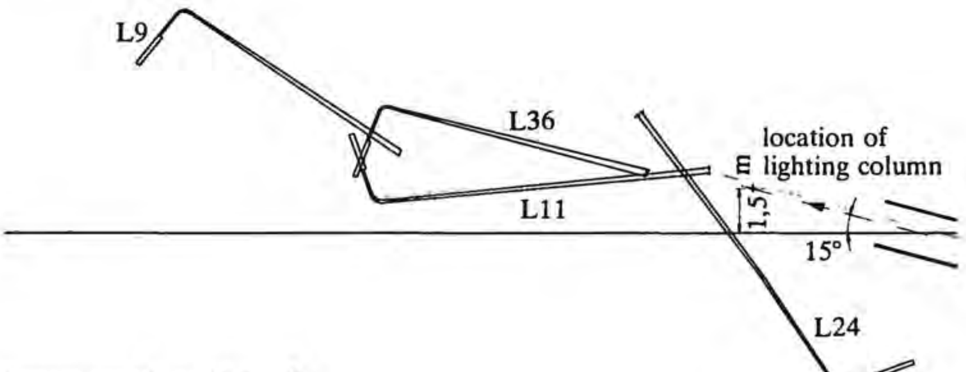
2.4. **Position of the fallen columns**

Test series A had already shown that none of the lighting columns would have fallen on the paved part of the road in an actual situation under the conditions then applicable (head-on impact, impact angle 10°, location of column 1 m from the imaginary edge of the road) (See SWOV, 1976).

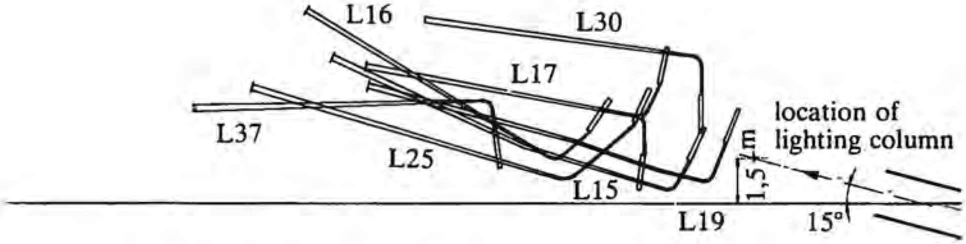
Figure 9 is a good indication for judging whether a lighting column would or would not have fallen on the carriageway. A division has been made into three speed categories: <35, approximately 45 and >55 km/h. All cases of low-aggressive columns (with which the ASI without seatbelts is <1) are included together with several columns for which the ASI was slightly over 1. The columns in test series A which satisfied these criteria are also included, but under the adapted conditions. It should be noted that these are columns that did not carry a lantern of the required weight.
The figure clearly shows that of the tested columns only one (L24) would have fallen a substantial distance (about 5.5 m) over the edge of the paved road section, and that it was in the lowest speed category. At higher speeds, columns did not fall over sideways after an impact because they have little resistance and the vehicle is still moving so fast after the impact that the bottom of the column is carried along by it. The columns then lie roughly in the vehicle's path.

2.5. **Electrical part**

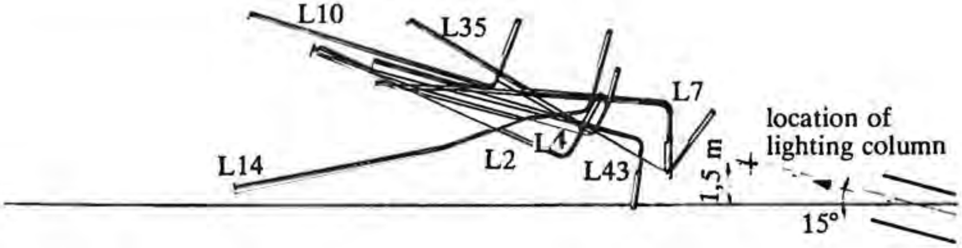
The columns tested in series A had no electrical equipment or ground cable.
In no case whatsoever in test series B or C, where these were fitted to examine the



impact speeds < 35 km/h



impact speeds approximately 45 km/h



Impact speeds > 55 km/h

Figure 9· *The position of low-aggressive columns after impact by categories: up to 35 km/h, approximately 45 km/h and over 55 km/h.*

potential danger caused by the mains supply, was it found that the vehicle or the column was electrified after the collision. It was found in some tests after the impact, however, that the electrical equipment or a bare end of cable was still live in cases where there had been no short circuit. If there had been a short circuit, analysis of high-speed films sometimes disclosed pronounced sparking. Where there was a short circuit, the main fuse was found to have blown.

In the case of the steel slip-design columns which slipped away, the ground cable was also sheared off at the height of the slip construction in every case. If there was no short circuit at the slip construction the bare end of the cable was still live.

As to the aluminium columns which broke, the general pattern was that the ground cable was ripped out of the electrical equipment. In some cases this was followed by short circuiting, and otherwise the bare cable end remained live. As to the aluminium columns which did not break, the door remained in position in most cases. It was thus impossible to come into contact with the mains supply in the column after the collision.

Note

In order to lessen the risk of electrocution or fire, a safety device could be fitted in the cable. Good experience has been gained with such devices in other countries when slip designs are used (Hignet, 1969).

2.6. **Other results**

2.6.1. *Soil resistance*

Table 1 compares the results of two sideways-on impact tests (L11 and L24) carried out also to obtain an idea of the effect of a 12 m slip-design steel column cutting through the soil. In both cases the impact speed was approximately 25 km/h.

In test L11 the soil was cut through about 20 cm, the vehicle having a mass of 710 kg, and in the other case, in which the vehicle's mass was 815 kg, it did not cut through the soil at all. In the test with the longer cut, the ASI was also higher (ASI without seatbelts in L11 was 0.8, and in L24 0.5). This may give the impression that if the soil is not compacted so firmly the resistance of a low-aggressive column increases. It should be added that in the test in which the ASI was lower the vehicle's mass was about 100 kg more than in the other. As the vehicle's mass increases, the resistance offered to it by the column becomes slighter and hence the difference between the two ASI's would have been less if both vehicles had had the same mass.

2.6.2. *Sideways-on as against head-on impacts*

The difference between the results of sideways-on and head-on impacts expressed as vehicle deceleration increases with the resistance of the column (See Table 2).

If the column has little resistance the consequences of both types of impacts will be about the same. As the column's resistance increases, the vehicle deceleration caused by the column will increase more in a sideways-on impact than in a head-on impact.

Test number	Impact type	Cut through soil	Speed km/h	Test vehicle Type	Mass	ASI without seatbelts
L 11	sideways-on	19 cm	23	Opel	710 kg	0.8
L 24	sideways-on	nil	25	Opel	815 kg	0.5

Table 1. *Results of impact tests with various degrees of cutting through soil. Type of column: 12 m steel column with slip design.*

Test number	Impact type	Column type	Speed km/h	Test vehicle Type	Mass	ASI without seatbelts
Slight column resistance						
L19	head-on	1)	46	VW	820 kg	0.4
L15	sideways-on	1)	40	VW	790 kg	0.3
More column resistance						
L36	head-on	2)	30	Opel	740 kg	0.6
L42	sideways-on	2)	29	Opel	780 kg	0.9
Great column resistance						
L37	head-on	2)	50	Opel	730 kg	0.9
L41	sideways-on	2)	50	Opel	810 kg	1.7

1) 12 m slip-design steel column
2) 10 m aluminium column

Table 2. *Resistance of column in sideways-on and head-on impacts.*

As a rule, if a sideways-on impact ends all right then this will certainly be the case with a head-on impact.

2.6.3. *Test vehicle types*

A difference in behaviour as between front and rear-engine vehicles was found in sideways-on impacts only. In such impacts the car rotated slightly around the impact point and the end of the car containing the engine slid further in the direction of movement.

3. Differences in results between 10 m aluminium columns in test series A, B and C

3.1. General

In 1971, SWOV made several impact tests with steel lighting columns with and without a slip design, and with aluminium columns (test series A). The conclusion from this series was that a 10 m aluminium column was 'low aggressive' enough and that a 12 m one just about meets the requirements.
The tests subsequently made by SWOV with both heavier aluminium columns (test series B) and lighter ones (test series C) produced poorer results.
This discussion will indicate the differences between the A series on the one hand and the B and C series on the other. It will be confined to the 10 m aluminium columns since it is these which would be expected to be low-aggessive for private cars.

3.2. Differences in design and execution of test series A and test series B and C

Table 3 gives the differences between test series A and test series B and C.
It is difficult to quantify the influence of the factors mentioned above. It can, however, be indicated whether the influence of some factors is assumed to be great or small.
All the factors adversely affected the aggressiveness of the columns tested in series B and C as compared with the findings in series A. Exceptions were the depth of the cable opening below ground level, where the influence of this position was better for the resistance of the columns tested in series B and C, and the dimensions of the columns in series C.
A factor that had little or no influence was the impact angle of 10° or 15° and the presence or not of a ground cable, since a cable offers resistance only if the column is already broken.

3.3. Factors assumed to influence the aggressiveness of the column

3.3.1. *Base diameter*

If the material properties remain unchanged when the base diameter and wall thickness are reduced, it can be assumed that the aggressiveness of the column will decrease. If this had been the only changed parameter in the tests, the results of test series C should have been better than those of test series A.

	Test series A	Test series B and C
Column (10 m)		
Base diameter/wall thickness (mm)	190/4	200/4, 220/3.75 and 175/4
Location of door opening	100 cm above ground level	60 cm above ground level
Location of cable opening	40 cm under ground level	50 cm under ground level
Electrical equipment	No	Yes
Lantern fitted	Yes, not the required weight	Yes, dummy arm, required weight (10 kg)
Ground cable	No	Yes
Sand in column	No	Yes, to ground level
Testing method		
Vehicle mass	850-900 kg	Average 770 kg
Impact angle	10°	head-on and sideways-on
Compactness of soil around column	great; well vibrated	great; partition behind column plus vibration
Recording		
Method	1. film analysis, being about 10% lower than electronic recording 2. ASI determined without lateral deceleration	electronic recording

In test series A the columns after planting were not filled with sand to ground level. When the series A tests were carried out it was not the customary practice to fill the columns with sand. This became the normal method in later years with the object, inter alia, of preventing corrosion and making the column more stable.
In test series B and C, therefore, the column was filled with sand to ground level through the door opening.

Table 3. *Differences between test series A and test series B and C.*

3.3.2. *Electrical equipment*

Fitting an electrical equipment increases the mass and also the inertia of the lower part of the column, which will have increased the aggressiveness of the columns tested in series B and C. But the influence of the electrical equipment is slighter than that of the other factors discussed in this sub-section.

3.3.3. *Filling the column with sand*

In Tables A and C (pp. 52 and 56) the results of test series A can be compared with those of series C. The comparison also includes the result of an impact for testing the equipment for sideways-on impacts (LT, see Table B, p. 54). No decelerations were recorded in this test.
The columns tested in series A as well as that used for the sideways-on impact were not filled with sand. In the test impact the soil was cut through further than in the other tests because it had not been compacted enough.

Comparison of the test results shows three striking features.
Firstly: Comparison of the ASI's for the 10 m aluminium columns tested head-on in series A (L2, L7, L9, L10) and those tested in series C (L35, L36, L37, L43) shows that the ASI is lowest at the lowest impact speed (30 km/h) in series C (L36). The head-on test in series C at 50 km/h (L37) gives the same ASI as similar tests in series A at 35 km/h and 60 km/h (L9 and L10). At higher speeds in series C, the ASI's are also higher than at lower speeds, in contrast to the higher speeds in series A where, in fact, the ASI decreases.
Secondly: in all the series A tests mentioned the column fractures near the cable opening. In two cases the column was intact at this point, and in two others partly broken. In the latter case the bottom bent over 90° through being run over and was pushed into the sand.
Thirdly: In the sideways-on impact with a column not filled with sand, whose base diameter/wall thickness was 190/4 mm, the column did break off at the bottom of the door opening, but not at the cable opening. The bottom of the column which stood at an angle because it cut through the soil offered so much resistance to the car that it overturned.

The greater resistance of the column at higher impact speeds was caused by the sand in the root section of the column, and by the fact that the columns did not break at the cable opening.
The fact that the sideways-on impact with the sand-filled column did not break the column at the cable opening is due partly to a different play of forces in lateral impacts than in head-on impacts and partly to the greater cutting through the soil.

3.3.4. *The test vehicle's mass*

The difference in mass between the vehicles in test series A and in test series B and C (about 100 kg) worked to the disadvantage of the columns tested in the latter series. The literature on impact tests, and also the laws of mechanics show that as the vehicle's mass increases it will be decelerated less by the column.

Figure 10. *In head-on tests with 10 m aluminium columns not filled with sand the columns broke off at the bottom of the door opening; the root sections were torn about 30 cm out of the ground and broke entirely or partly at the level of the cable opening.*

Figure 11. *In tests with sand-filled columns the column also broke off at the level of the door opening. The root section however was pulled only slightly out of the ground; it did not break off but folded over at ground level.*

As the breaking of the column is a dynamic process involving visco-elastic effects, the influence of the lower mass cannot automatically be expressed as a factor. The higher ASI's at higher impact speeds in series C as compared with series A can not be attributed solely to the difference in vehicle mass, since this is only about 10%.

3.3.5. *Records*

Table 3 has already indicated that recording of the average deceleration by means of film analysis used in test series A is about 10% less than the electronic recording in series B and C. This difference was noted in series B when vehicle decelerations in various head-on tests were recorded by both methods and afterwards compared. In one case (L26) the difference is shown in a graphic in Figure 12. The broken line indicates the record made by the old film analysis method also used in series A; the dotted line shows the electronic record. The continuous line also indicates how more accurate film analysis is possible with an improved analysis method. The average vehicle deceleration needed for calculating the ASI was determined from the curves as the average deceleration during 50 ms. The difference between the average decelerations by electronic recording and those by the 'old' film analysis method proved to average 10%. In Table A, these differences have been taken into account in test series A.

The influence of the fact that lateral deceleration was not measured in series A does not seem to be very great in calculating the ASI. The minor difference is covered by the 10% indicated above.

Consequently, the recording method had no further influence on interpretation of the ASI values.

3.4. **Discussion**

In order to clarify the differences in the results of impact tests in series A and C, it is necessary to indicate what happens during an impact.

During a collision the column comes under a bending load. If the load is high, the column will break off at the door opening.

In sideways-on impacts, the point of contact will be higher than in head-on collisions because the forces are spread over a greater length (or height). In a sideways-on impact, therefore, the column will be more inclined to break off at the *top* of the door opening and in a head-on collision at the *bottom*.

At the same time, the bending of the column tends to pull out the root section. The less the resistance this root section encounters, the more easily it will be dragged out of the ground. It may be lifted so high that the weakest point – the cable opening – practically reaches ground level, causing strong bending and shearing forces at this point and forming a second potential breaking point. If there is no sand in the root section it will deform more readily (for instance bend sharply) leading to rupture if the walls are relatively thin.

If the processes that took place in the series A and C impact tests are considered in the light of the above hypotheses, the following is found.

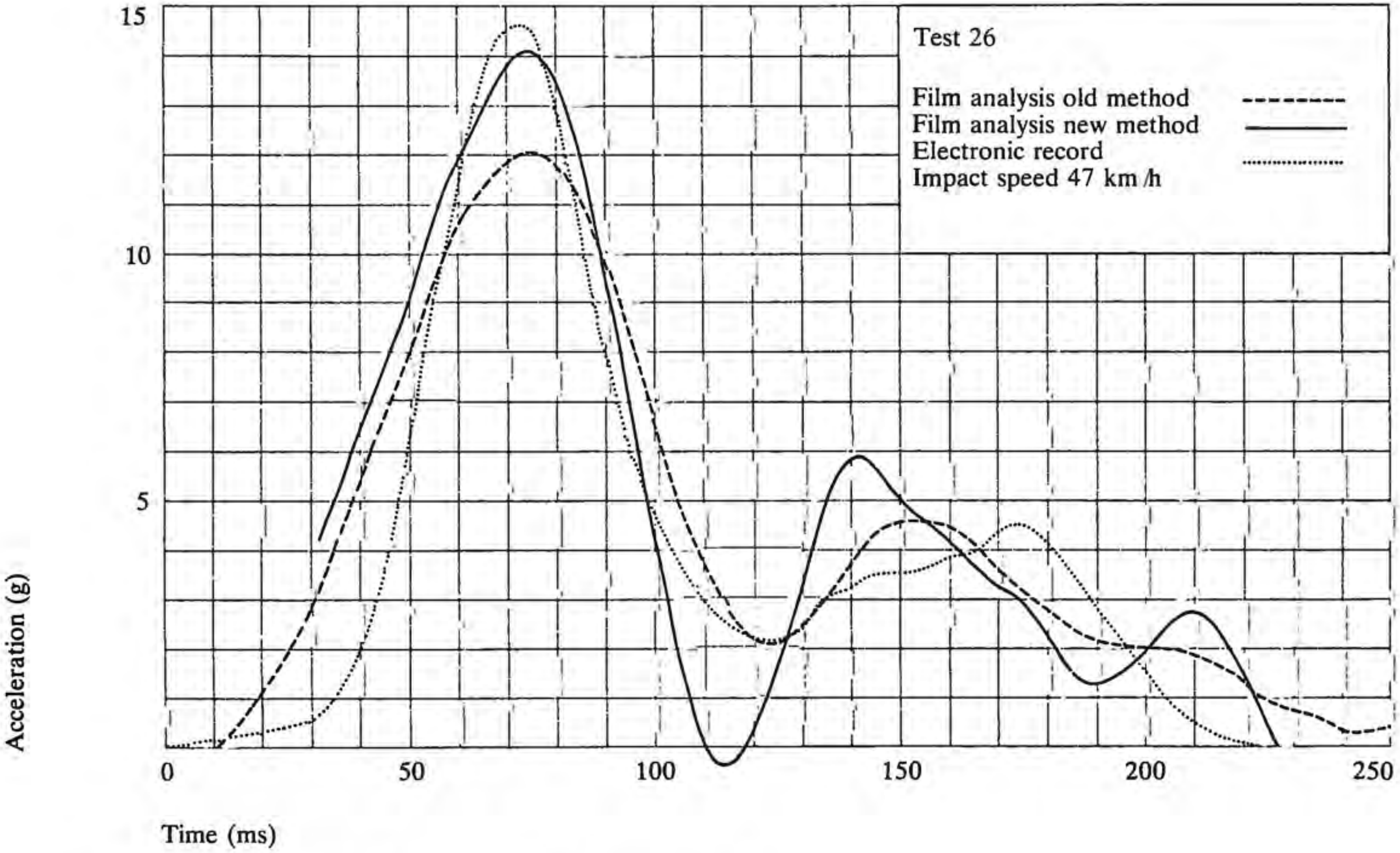


Figure 12. *Deceleration curves per electronic recording and two film-analysis methods.*

Figure 13. *In head-on tests with 10 m aluminium sand filled columns, the root section was only bent over at the height of the cable opening so that the bottom of the column stood upright at an angle. Because of the low impact speed, the vehicle came to a stop against the stump.*

In series A, *head-on* tests with 10 m aluminium columns *not filled with sand* (L2, L7, L9 and L10), the columns broke at the bottom of the door opening and the root sections were pulled about 30 cm out of the ground by the tensile forces resulting from the bending of the column. Owing to the subsequent bending and shear forces, the root sections broke off completely at the cable opening at higher speeds and broke about three-quarters at lower speeds. In the latter cases the root section folded over 90° and the vehicle drove right over it.

In test series C, *head-on* tests with 10 m aluminium *sand-filled* columns (L35, L36, L37, L43), the column was also put under a bending load. The bending broke the column at the bottom of the door opening. The great mass of the (sand-filled) root section stopped the column being pulled up. This sand filling also prevented a fracture being initiated at the height of the cable opening (for instance by bending over), and hence there was little fracture at this point. In consequence, the longitudinal vehicle deceleration was high. The root section only bent over at the height of the cable opening, and the bottom of the column stood at an angle. In the lowest-speed test (L36) the bottom of the column still offered so much resistance that the vehicle came to a stop against it (See Figure 13).
In the other tests the root section was pushed so far into the sand that the vehicle ran right over it. The fact that the ASI remained far below unity in test L36 (ASI without seatbelt = 0.6) was due to the low vertical deceleration and column and vehicle deformation.

In the *sideways-on* impacts in series C, the columns that broke were broken at the top of the panel door opening. There was no breakage at the height of the cable opening. As the part of the column under the point of breakage was not flattened against the ground, the vehicle met so much resistance that it overturned.
In *sideways-on* impact with a column *not filled with sand* with the dimensions as in test series C, the root section is likely to be pulled so far out of the soil first (analogously to series A) that the cable opening comes to about ground level. But the possibility remains that the vehicle (which will have to apply the bending and shearing force to the root section in order to break it) will encounter so much resistance from this section that it will overturn.

Conclusions

The base diameter of the 10 m aluminium columns tested in series C was smaller than in series A, and it can therefore be assumed that the series C columns would offer less resistance to an impact. The fact that the series A columns nevertheless showed good results can be attributed primarily to two factors: the fact that the columns tested in series A were not filled with sand and the greater vehicle mass in this series.

4. Summary

Series of impact tests were conducted in order to examine the behaviour of lighting columns in (sideways-on or head-on) impacts by private cars. The resistance met with by the vehicle in hitting the column, the denting of the passengers' compartment, the location of the columns after the impact and the influence of the electric current during and after the impact were investigated.

The results should be considered with some reserve since they are based on a standard (the ASI) which has not (yet) been established on an entirely sound scientific basis. It was nevertheless used because it is the best available so far since it combines longitudinal, lateral and vertical vehicle decelerations.
In order to compare the resistance of columns in head-on and sideways-on impacts expressed as vehicle decelerations, the direction of longitudinal deceleration for calculating the ASI in all tests was taken as the vehicle's direction of movement. In sideways-on impacts, however, the risk of serious injury is then underassessed as compared with head-on impacts with the same ASI value. In other words: in sideways-on impacts, an ASI calculated in this way should be slightly less than unity because there is then no risk of serious injury.

It was found that a car meets little resistance from the column if the shaft of the column is easily separated from the root section at about ground level. This proved to be attainable by providing the columns with a special safety design or by making them break at the base by utilising the material properties of aluminium.

All the *10 and 12 m steel columns with a slip design* amply satisfied the criterion for determining the vehicle deceleration for car occupants without seatbelts. An exception was a 12 m column with extra long arms, of 3 m. The resistance offered by this column in an impact was just a little too great. A very important feature as regards slip-design columns was the height of the slip construction above ground level. It must in any event be less than 10 cm; the 3 cm height used in the impact tests caused no problems.

From comparison of the results of test series A and of test series B and C, it is assumed that *10 m aluminium columns* with a base diameter/wall thickness of 175/4 mm will satisfy the ASI criterion for car occupants *without* seatbelts in a *head-on* collision, provided such columns are not filled with sand.
In *sideways-on* impacts, these columns cause a combined vehicle deceleration about equal to or greater than unity. The risk of injury is then greater than with comparable ASI's for head-on impacts, having regard to the calculating method applied. Nor is it ruled out that the vehicle overturns in a sideways-on impact with such a column. (For occupants with seatbelts such 10 m columns will satisfy the ASI criterion, but the above restrictions apply here too).

The columns last tested in series C, however, did not yet meet the 4% deflection standard as regards static strength. By changing the length of the column sections, these columns can ultimately be expected to meet this requirement.

The *12 m aluminium columns* will *not* satisfy the ASI criterion in a collision in which the car occupants are not wearing seatbelts.

The single test with the *polyester column* showed that it offered too much resistance to the impacting vehicle under the test conditions. To ensure low resistance, such a column, like the aluminium columns, should break off at about ground level. This is unlikely with this column which would have to be made more robust still with a view to its static strength.

For the slip-design steel columns, somewhat too much *denting of the flank* was found in two sideways-on impacts. Taking the poorer quality of the test vehicles into account, this is still acceptable however. In the case of the aluminium columns, a bigger dent was measured, which is barely acceptable even taking the quality of the vehicles into account.
The passengers' compartment was not reduced in size in any of the head-on collisions.

The *dent caused in the roof by falling columns* was not deeper than 7 cm, which is slightly less than an American standard allows. It can be stated that a falling column up to a mass of about 150 kg will cause little danger to occupants of hard-top cars. A falling column may, however, be dangerous to occupants of open cars, of which there are few in the Dutch vehicle park.

As to *the position of the columns after an impact* it is only likely at low impact speeds (about 35 km/h or lower) that low-aggressive columns may fall on to the carriageway following an impact. At higher speeds it was not found on any occasion that the column fell on the carriageway. The general pattern at such higher speeds was that the column fell roughly into the vehicle's path after the impact.

The tests have shown that a 220 V electricity supply connected to the electrical equipment may be dangerous in two ways. Firstly by sparking in cases of short-circuiting. Such sparks may form a potential fire hazard if, for instance, a petrol pipe is hit. Fire did not, in fact, break out in any of the tests. Secondly, the current still supplied to a bare cable end or the electrical equipment may be dangerous if these places are touched after an accident. But in no case was it found that the vehicle or the lighting column was electrified after an impact. In order to lessen the risk of electrocution or fire in view of the above hazard, a safety device could be fitted in the cable. Experience with such safety devices in other countries has been favourable.

As regards car occupants *not* wearing seatbelts, the following conclusions can be drawn:

- 10 and 12 m rigid steel columns are too aggressive to private cars.
- 10 and 12 m steel columns with a slip device are low aggressive for private cars.

- As regards 10 m aluminium collumns, it is assumed that these are only low-aggressive in head-on collisions, provided the root section is not filled with sand. In sideways-on impacts they are too aggressive, especially taking into account the risk of injury being greater than might be presumed from the calculated ASI's, but also because there is a danger of the car overturning and there is comparatively severe denting of the passengers' compartment.
- 12 m aluminium columns are too aggressive to private cars.

Some notes

The design of lighting columns would need to be considered less critically as regards their crash aspects if it could be assumed that *all* car occupants wore seatbelts. But as long as this is not the case, for instance because in the Netherlands compulsory seatbelt wearing does not apply to everyone (for instance rear-seat occupants and occupants of cars built before 1971 are excluded), it had to be investigated in the first place which lighting columns satisfied the ASI criterion and which did not when hit by cars whose occupants do *not* wear seatbelts.

For a collision with a 10 m aluminium column to have no serious consequences it was found to be essential that the part of the column in the soil should break near the cable opening. The results of test series A and C showed that breakage at this point was very probably prevented by the amount of sand in the root section of the column. If the cable opening is about 50 cm below ground level, as in the tests, the root section of an aluminium column must *not* be filled with sand if an accident is to have no serious effects. If the cable opening is higher, or if a weaker point at about ground level can be made in some other way, the sand in the column will have less effect. As there was no possibility, however, of making more tests without sand in the root section, the influence of the sand could not be quantified more precisely.
The tests with aluminium columns showed that if they break near the door opening and not near the cable opening, the stump of the column which is then still about 60 cm above ground level may be flattened against the soil. This was found with 10 and 12 m aluminium sand-filled columns. In head-on impacts, the vehicle will run completely over this root section, but in sideways-on impacts the section may be so resistant that the vehicle will overturn.
As regards the location of the cable opening, the aggressiveness of an aluminium column is assumed to decrease the higher the opening is placed. The tests gave no grounds for assuming that placing the cable opening and the door opening elsewhere in the circumference of the column would lessen its aggressiveness.

An impact test showed that an aluminium column that splits on impact (for instance owing to a defect in manufacture) may break off in a totally different way. This may not only greatly influence impact characteristics, but it cannot be predicted where the column will fall. It could not be checked whether this was merely an exception.

In the case of slip-design columns, two tests gave the impression that they slip off somewhat later if the soil is not well compacted, thereby slightly increasing the column's resistance to an impact.
The difference between the results of sideways-on and head-on impacts expressed as

vehicle deceleration increases with the resistance of the column. If the column has little resistance the severity of the consequences of both type of impacts will be about the same. As the resistance of the column increases, the vehicle's deceleration in a sideways-on impact will increase more than in a head-on impact. On the whole it can be said that if a sideways-on impact has no serious consequences, this will certainly also be the case with a head-on impact.

The two types of test vehicles (front and rear engines) revealed no notable differences in the impacts.

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**Only in Dutch*

Tables A, B and C

Test No.	Column						Test vehicle		Impact	
	mate-rial	l.p.h./a.l(m)	slip design 1)	diameter/wall thickness (mm)	mass (kg)	deflection in static test (%) 2)	make and type	mass (kg) 3)	type	spee (km/
L1	Fe	10/1.5	–	178/5	200	2	Opel Rekord 1700	± 900	Head-on	93
L2	AL	10/1.5	–	190/4	62	3	Opel Rekord 1700	± 900	Head-on	66
L3	AL	12/1.5	–	210/5	100	3	Opel Rekord 1700	± 900	Head-on	100
L4	Fe	10/1.5	yes	178/5	175	2	Opel Rekord 1700	± 900	Head-on	78
L5	Fe	10/1.5	–	178/5	200	2	Opel Rekord 1700	± 900	Head-on	105
L6	AL	12/1.5	–	210/5	100	3	Opel Rekord 1700	± 900	Head-on	70
L7	AL	10/1.5	–	190/4	62	3	Opel Rekord 1700	± 900	Head-on	93
L8	Fe	10/1.5	–	152/4.5	160	3	Opel Rekord 1700	± 900	Head-on	82
L9	AL	10/1.5	–	190/4	62	3	Opel Rekord 1700	± 900	Head-on	35
L10	AL	10/1.5	–	190/4	62	3	Opel Rekord 1700	± 900	Head-on	60

1) l.p.h. = light-point height; a.l. = arm length

2) deflection as percentage of light-point height (manufacturers' figures)

3) not measured – as listed by maker

Table A. *Details of columns, test vehicles, type and speed of impact, and results for ASI (without and with seatbelts), deformation of columns and vehicles in test series A (L1 to L10).*

SI		Column				Test vehicle				Notes
ithout atbelt	with seatbelt	slipped off	broken at cable opening	broken at door opening	bent over at ground level	stopped against column	dented (external) front (cm)	flank (cm)	roof (cm)	
0	1.1	–	–	–	–	–	48	–	–	column pulled right out of soil
7	0.4	–	yes	bottom	–	–	40	–	6	–
5	0.9	–	–	bottom	–	–	50	–	–	–
.7	0.4	yes	–	–	–	–	41	–	7	torque 250 Nm
.3	1.3	–	–	–	–	–	62	–	–	column pulled right out of soil
6	1.0	–	–	bottom	–	–	52	–	–	–
6	0.4	–	yes	bottom	–	–	37	–	–	–
.9	1.1	–	–	–	–	–	57	–	–	column pulled right out of soil
.9	0.5	–	–	bottom	–	–	40	–	–	–
.0	0.6	–	–	bottom	–	–	40	–	2	–

Test No.	Column						Test vehicle		Impact	
	mate-rial	l.p.h./ a.l(m) 1)	slip design	diameter/ wall thickness (mm)	mass (kg)	deflection in static test (%) 2)	make and type	mass (kg) 3)	type	speed (km/h)
LT	AL	10/1	–	190/4	n.k.**	n.k.**	Opel Kadett	740	Sideways-on	53
L11	Fe	12/1.5	yes*	178/4.5	181	3.2	Opel Kadett	710	Sideways-on	23
L12	Fe	10/1.5	–	165/4.5	130	2.7	Opel Kadett	790	Sideways-on	55
L13	Fe	12/1.5	yes*	178/4.5	181	3.2	Opel Kadett	720	Sideways-on	63
L14	Fe	12/1.5	yes	178/4.5	181	3.2	Opel Kadett	785	Sideways-on	57
L15	Fe	12/1.5	yes	178/4.5	181	3.2	Volkswagen 1200	790	Sideways-on	40
L16	Fe	10/1.5	yes	165/4.5	137	2.7	Volkswagen 1200	790	Sideways-on	42
L17	Fe	10/2x1.5	yes	165/4.5	146	n.k.**	Volkswagen 1200	840	Sideways-on	40
L18	AL	12/1.5	–	250/4	113	3.9	Volkswagen 1200	835	Head-on	47
L19	Fe	12/1.5	yes	178/4.5	181	3.2	Volkswagen 1200	820	Head-on	46
L20	AL	12/1.5	–	250/4	113	3.9	Opel Kadett	815	Sideways-on	27
L21	AL	10/1.5	–	220/3.75	84	2.9	Volkswagen 1200	835	Sideways-on	45
L22	Pol.	10/1.5	–	275/10	128	5.4	Volkswagen 1200	765	Sideways-on	45
L23	AL	10/1.5	–	200/4	77	4.0	Volkswagen 1300	785	Sideways-on	43
L24	Fe	12/1.5	yes	178/4.5	181	3.2	Opel Kadett	815	Sideways-on	25
L25	Fe	12/3	yes	219/4	215	4.0	Opel Kadett	755	Sideways-on	41
L26	AL	12/3	–	275/4	132	4.4	Volkswagen 1300	885	Head-on	47
L27	AL	10/1.5	–	220/3.75	84	2.9	Volkswagen 1200	765	Head-on	26
L28	AL	10/1.5	–	220/3.75	84	2.9	Volkswagen 1200	835	Head-on	43
L29	AL	10/1.5	–	220/3.75	84	2.9	Volkswagen 1200	830	Head-on	61
L30	AL	10/1.5	–	200/4	77	4.0	Volkswagen 1200	805	Head-on	46

1) l.p.h. = light-point height; a.l. = arm length

2) deflection as percentage of light-point height, determined experimentally.

3) found by weighing

4) b = bottom; t = top

5) r.o. = roll over

*) slip design 10 cm above ground level.

**) n.k. = not known

Table B. *Details of columns, test vehicles, type and speed of impact, and results for ASI (without and with seatbelts), deformation of columns and vehicles in test series B (LT, L11 to L30).*

ASI		Column				Test vehicle				Notes
without seatbelt	with seatbelt	slipped off	broken at		bent over at ground level	stopped against column	dented (external)			
			cable opening	door opening			front (cm)	flank (cm)	roof (cm)	
n.k.**	n.k.**	–	–	b4)	–	r.o.5)	–	17	–	soil not firmly compacted
0.8	0.5	yes	–	–	–	–	–	18	–	soil not firmly compacted
3.5	2.0	–	–	–	–	yes	–	55	–	
2.4	1.4	yes	–	–	–	–	–	75	–	vehicle stopped on lower flange
0.5	0.3	yes	–	–	–	–	–	18	5	
0.3	0.2	yes	–	–	–	–	–	10	–	
0.3	0.2	yes	–	–	–	–	–	11	6.5	
0.3	0.2	yes	–	–	–	–	–	7	7	
1.3	0.8	–	–	b	–	–	11	–	–	ASI calculated from film, §1.8.
0.4	0.2	yes	–	–	–	–	5	–	1	ASI calculated from film, §1.8.
± 1	< 1	–	–	–	–	yes	–	32	–	ASI estimated; see §1.8.
> 1	± 1	–	–	–	–	yes	–	35	–	ASI estimated; see §1.8.
> 1	± 1	–	–	–	–	yes	–	43	–	ASI estimated; see §1.8.
> 1	± 1	–	–	–	–	yes	–	38	–	ASI estimated; see §1.8.
0.5	0.3	yes	–	–	–	–	–	13	3.5	
1.1	0.6	yes	–	–	–	–	–	30	–	
1.7	1.0	–	–	b	–	–	10	–	–	
1.3	0.7	–	–	b	–	yes	7	–	–	
1.3	0.7	–	–	–	yes	yes	8	–	–	
1.4	0.8	–	–	–	yes	yes	10	–	–	
1.0	0.6	–	–	b	–	–	9	–	–	

Test No.	Column						Test vehicle		Impact	
	material	l.p.h./a.l(m) 1)	slip design	diameter/wall thickness (mm)	mass (kg)	deflection in static test (%) 2)	make and type	mass (kg) 3)	type	speed (km/h)
L31	AL	10/1.25	–	175/4	63	4.4	Opel Kadett	740	Sideways-on	41
L32	AL	10/1.25	–	175/4	63	4.4	Opel Kadett	820	Sideways-on	30
L33	AL	10/1.25	–	175/4	63	4.4	Opel Kadett	765	Sideways-on	60
L34	AL	12/1.25	–	200/5	100	4.5	Opel Kadett	740	Sideways-on	45
L35	AL	10/1.25	–	175/4	63	4.4	Opel Kadett	705	Head-on	64
L36	AL	10/1.25	–	175/4	63	4.4	Opel Kadett	740	Head-on	30
L37	AL	10/1.25	–	175/4	67	4.2	Opel Kadett	730	Head-on	50
L38	AL	12/1.25	–	200/5	100	4.5	Opel Kadett	695	Head-on	67
L39	AL	12/1.25	–	200/5	100	4.5	Opel Kadett	740	Head-on	49
L40	AL	10/1.25	–	175/4	63	4.4	Opel Kadett	815	Sideways-on	54
L41	AL	10/1.25	–	175/4	63	4.4	Opel Kadett	810	Sideways-on	50
L42	AL	10/1.25	–	175/4	63	4.4	Opel Kadett	780	Sideways-on	29
L43	AL	10/1.25	–	175/4	63	4.4	Opel Kadett	780	Head-on	76

1) l.p.h. = light point height; a.l. = arm length
2) deflection as percentage of light-point height, determined experimentally
3) found by weighing
4) b = bottom; t = top
5) r.o. = roll over
*) sand in column to 50 cm above ground level

Table C. *Details of columns, test vehicles, type and speed of impact, and results for ASI (without and with seatbelts), deformation of columns and vehicles in test series C (L31 to L43)*

ASI		Column				Test vehicle				Notes
without seatbelt	with seatbelt	slipped off	broken at cable opening	door opening	bent over at ground level	stopped against column	dented (external) front (cm)	flank (cm)	roof (cm)	
1.4	0.8	–	–	t4)	–	r.o.5)	–	28	–	sand in column*
0.9	0.5	–	–	–	–	yes	–	26	–	sand in column*
1.4	0.8	–	–	t	–	r.o.5)	–	37	3	sand in column*
1.7	1.0	–	–	t	–	yes	–	32	–	
1.2	0.7	–	–	b4)	–	–	33	–	–	
0.6	0.4	–	–	b	–	yes	33.5	–	–	
0.9	0.5	–	–	b	–	–	34	–	–	
1.7	1.0	–	–	t	–	–	38	–	4	
1.4	0.8	–	–	b	–	part.	30	–	<1	
1.3	0.8	–	–	t	–	yes	–	33	7	Column split over full length
1.7	1.0	–	–	t	–	r.o.5)	–	30	33	
0.9	0.5	–	–	–	–	yes	–	23	–	
1.1	0.6	–	–	b	–	–	28	–	–	